APPLICATION OF GAMMA IRRADIATION
FOR THE
DISINFECTION OF MUNICIPAL WASTE EFFLUENTS

DIVISION OF RESEARCH
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APPLICATION OF GAMMA IRRADIATION FOR THE DISINFECTION OF MUNICIPAL WASTE EFFLUENTS

By

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Introduction

Gamma irradiation has been used for some time as a sterilizing agent in the processing of drugs and pharmaceuticals, and more recently in the preparation of certain foods. Since the cost of isotopes and isotope installations has moderated from initial levels, it has been used on a wider scale for the sterilization of hospital supplies.

Standard methods of sewage treatment presently in use in large urban areas are not entirely effective in the inactivation of pathogenic micro-organisms (1); for example, it has been estimated that as many as 7 to 70 enteric viruses per litre could remain in the effluent from such a plant (2), even with post-chlorination. As an indication of the degree of contamination which can be produced, one quarter of the samples of river water in a metropolitan area, showed the presence of pathogenic viruses (3,4). The importance of the presence of these micro-organisms, potentially capable of causing widespread disease, increases as the demand for potable water supplies necessitates re-use of water.

This report contains the results of research into the use of gamma irradiation in the disinfection of sewage effluent, which forms part of a continuing study into the application of gamma irradiation in water and wastewater treatment.

Experimental

1. Materials and Equipment

(a) Irradiation Equipment

Irradiation was carried out in a Gammacell 220* (Figure 1) supplied by Atomic Energy of Canada Ltd., Commercial Products Division. The unit contains ^{60}Co sources capable of emitting approximately 3.2×10^4 rads per minute, within a lead-shielded chamber into which sample containers can be lowered by an elevator system. Samples were irradiated in 400 ml capacity polyethylene containers (Figure 2) simulating a batch-type system; no provisions were made for stirring the samples during treatment. Other workers (5) had reported good disinfection at a total dose of 2.5×10^5 rads. In the Gammacell 220, this would correspond to an exposure time of about 7 minutes. In this series of experiments, the actual dose used was 2.35×10^5 rads.

(b) Sewage

Domestic sewage from a residential area was obtained directly from a sewer line within the laboratory building; the sewage contained no industrial waste. The sewage effluent used in the irradiation tests was obtained by processing this sewage in the laboratory, in a continuous flow, model scale biological treatment unit; the flow rate

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was approximately 30 ml per minute with a retention time of approximately 8 hours. The quality of the effluent fluctuated due to problems experienced in the operation of the unit, and as a result of variations in the strength of the feed. Both good and poor quality effluents were subjected to irradiation.

2. Analytical Methods

(a) Bacterial Enumeration

All bacterial counts were carried out using the Millipore filter method (6) using 0.45^{μ} pore size, 47 mm diameter filters, after suitable dilution of the samples. Total counts were carried out on black filters using m-plate count medium (Difco) after incubation at 35°C for 24 hours. Enterococcus and total coliform counts were completed on white filters, the former being incubated at 35°C for 48 hours on m-enterococcus medium (Difco) and the latter for 24 hours on m-endo medium (Difco): in each case only typical colonies were counted. For the spore counts, 5 ml aliquots of undiluted samples were heated to 85°C for 15 minutes to inactivate non-sporing organisms; heat-treated samples were then filtered through black filters and incubated at 35°C for 24 hours on m-plate count medium.

(b) Bacteriophage (Virus) Counts

Numbers of E coli B bacteriophage were estimated using the most probable number (MPN) method of Kott (7), except that lauryl tryptose broth with no added calcium was used (8), instead of phage assay broth. Untreated sewage was diluted 1/1000, plant effluent and irradiated effluent 1/10, before assay.

(c) Chemical Analysis

Samples of untreated sewage, sewage effluent and irradiated sewage effluent were analysed for BOD, COD, TOC, detergents (methylene blue active substances, MBAS) total nitrogen and nitrite. Phosphorus analysis was undertaken on some samples. All analyses were completed according to Standard Methods (6).

(d) Algal Growth Experiments

In order to study the algal growth potential of the sewage effluents treated by gamma irradiation, the sewage effluent directly from the model plant was used as a control. For treatment, effluent was either subjected to irradiation at 2.35 x 10^5 rads, filtration through a diatomaceous earth (DE) filter, or to irradiation followed by DE filtration. The DE used was swimming pool grade (Dicolyte Speed X) and filtration was achieved without vacuum, under a vertical head of no more than 2 in., through a DE layer approximately 1/4 in. thick formed on a fibreglass filter held in a Buchner funnel.

Aliquots of the three treated effluents and the untreated control, were diluted tenfold in lake water (Gull Lake, Ontario) which had been filtered through a 0.45μ Millipore filter (Millipore Filter Corporation, Bedford, Massachusetts, U.S.A.); this dilution procedure was undertaken to simulate the effect of discharge of the effluents into a body of natural water. To 500 ml portions of the various effluents and their dilutions, uniform inocula of the alga Chlorella pyrenoidosa were added and all samples were incubated at 23°C for 14 days in a growth chamber under "White" light on a shaker table. Chlorophyll a determinations were carried out on each culture, according to Standard Methods (6), as a measure of the extent of algal growth.

Results

The result of irradiation treatment of sewage effluent with respect to micro-organisms is shown in Table 1. The total bacterial count was reduced by three orders of magnitude by exposure to irradiation, whereas total coliforms were reduced to levels of less than 1 per ml. Enterococci and spore formers proved more resistant to the treatment than the coliforms, as had been found by others (9,10). In these experiments, bacteriophages were found in irradiated effluents.

From Table 2, it can be seen that gamma irradiation did not significantly alter any of the chemical parameters measured. There was a slight reduction in BOD upon irradiation, but this may have been due to inactivation of the organisms. A further series of tests was performed, in which the inoculum for the BOD test was seeded with fresh, settled sewage, and the results compared to unseeded duplicates. The comparisons are shown in Table 3, and indicate that the seeding procedure resulted in a slight increase in BOD over the unseeded, irradiated samples.

Table 4 shows the results of the chemical analyses carried out on the samples used in the algal growth experiments. They indicate that within the limits of experimental error, DE filtration and gamma irradiation have little effect on the parameters measured. Table 5 contains the results of chlorophyll measurements after growth of the algae in the various effluents. If only the undiluted effluents were considered, it would appear that algal growth, as measured by chlorophyll a, is inhibited in irradiated samples as compared to the control. However, there is very little difference in the algal growth obtained in any of the diluted samples.

Discussion

Gamma irradiation has been proposed as a possible alternative to chlorination in the disinfection of sewage effluents. A small plant has been in operation for some time in a campground (11), with an irradiator employed in conjunction with an extended aeration package plant, essentially as a polishing process; it was reported that algal bloom production was retarded in samples of irradiated effluents.

The results reported here show that gamma irradiation at a total dose of 2.35×10^5 rads at about 3.2×10^4 rads per minute, is a good disinfecting agent for sewage effluent; in general, reduction in micro-organism numbers are similar to those obtained with standard chlorination practices. The figures also show, however, that coliform organisms are among the most sensitive to the irradiation. As a result of this, they are not an accurate indicator of the efficiency of disinfection by such treatment; this has been concluded by other workers (12). There is an obvious advantage to the use of irradiation as a disinfectant procedure where there may be a limit imposed on the addition of chemicals for disinfection, as is the case in some European countries. Heretofore, the recommended alternative to chemical disinfection has been heat treatment (13) which has proven unreliable and costly. Complete inactivation of bacteriophage

was not obtained after passage of the effluent through the irradiator, although 100% kill had been previously reported at a similar dose (5). This discrepancy may be explained by the method of bacteriophage enumeration used, the MPN method being more sensitive for low numbers than the more usual plaquing method.

Bacteriophages have been used as models for the behaviour of other viruses, and therefore it can be concluded that gamma irradiation treatment at this dose level may not completely inactivate all enteric viruses present in the effluent, especially since all available evidence indicates that the latter are less sensitive to irradiation than bacteriophages.

From the chemical analyses presented, it can be seen that irradiation treatment produces little change in the parameters measured. Detergents measured as MBAS are effectively reduced more than 95% in the treatment plant and undergo no further reduction upon exposure to the irradiation. Total phosphorus in the effluent undergoes no reduction upon gamma treatment. The COD and TOC of the sewage are reduced in the plant, and are not significantly altered by irradiation at this dose. Nitrite in the effluent apparently increases upon irradiation, but the reason for this is not known. There is an apparent decrease in the BOD if the irradiated effluent is tested without seeding. This may, in part, be due to the

destruction of micro-organisms, and the effect is partly reversible if the test samples are seeded. The BOD would also be expected to decrease if some biodegradable components of the sewage were rendered non-biodegradable as a result of irradiation.

Gamma irradiation apparently causes an alteration in secondary sewage effluent, which results in retardation in the growth of algae inoculated directly into the effluent. The factor or factors causing this phenomenon were not determined, but it could be attributable to the formation of some toxic substance produced on irradiation. Upon discharge or dilution of the irradiated effluents, whether DE filtered or not, the inhibiting factor no longer exerts a retarding effect, and the same amount of algal growth occurs in irradiated and unirradiated samples. Irradiation would therefore not be expected to safeguard natural waters from potential eutrophication and algal bloom development due to the discharge of sewage effluents.

Although only certain parameters were measured in this study, and their change upon irradiation recorded, the treatment could additionally cause certain undesirable changes in the effluent which could prove deleterious when its ultimate disposal is considered. Other work in this laboratory

(K. Roberts, personal communication) has indicated that doses of gamma irradiation of this magnitude, applied to certain industrial-type wastes, render those wastes less amenable to biological treatment. If residues in irradiated effluents from municipal wastes have undergone similar changes, problems may arise in receiving streams, etc. due to a radiation-induced non-biodegradability.

Conclusions

Good disinfection of secondary effluent from a conventional aeration plant can be obtained by the application of a gamma irradiation dose of about 2.35×10^5 rads at about 3.2×10^4 rads per minute, utilizing a batch-type system; a continuous-flow system would be expected to give a similar result at the same total dose. Complete inactivation of bacteriophages (viruses) was not achieved at this dose level. Gamma irradiation did not produce any significant alterations in the measured chemical parameters of the effluents, with the possible exception of the increase detected in the nitrite concentration.

With this municipal waste, and a limited number of experiments, algal growth as measured by chlorophyll a, was apparently retarded in samples of irradiated effluent; no such effect was noted if the irradiated effluent underwent dilution before addition of the algae.

Recommendations

The estimated cost of an irradiation system (11) is considerably higher than that for an equivalent plant utilizing chlorination for disinfection. It has been stated that (14) "...radiation processes must demonstrate a distinct advantage over conventional processes with resulting equal or improved economics."

On this basis, although there may be certain conditions for its application, there appears to be no valid reason at this time for recommending the use of gamma irradiation for disinfection of sewage effluents in the place of conventional chlorination. However, concern has been expressed in some areas (S.W. United States, Germany) regarding the addition of large amounts of chlorine to such effluents and its effect on the receiving stream. Under such circumstances, where the addition of chemicals may be limited, gamma irradiation could be substituted.

To determine the effect of the application of irradiation on a pilot scale, further studies are proposed with an irradiator installed on a plant providing secondary sewage treatment.

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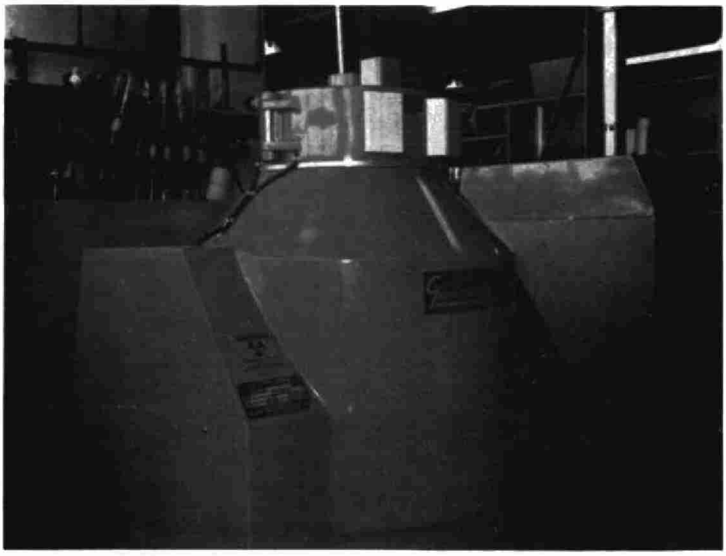

Fig. 1

Gammacell 220, Atomic Energy of Canada Limited.

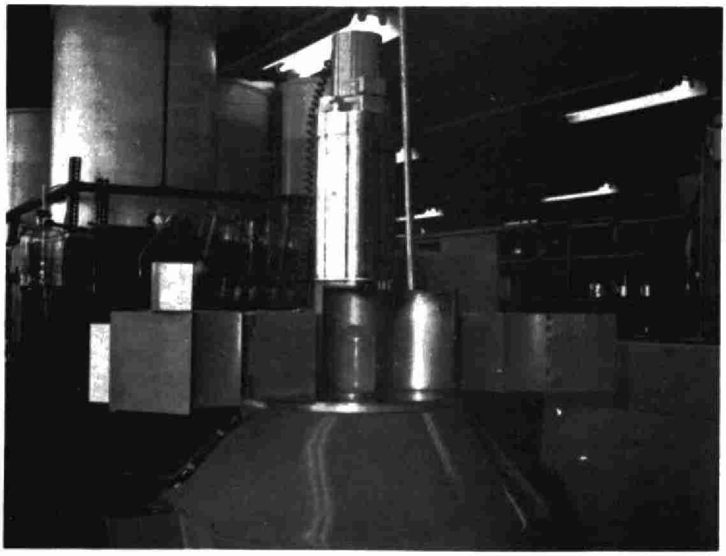

Fig. 2

Gammacell 220, with shield collar doors open to show elevator and sample container in position.

TABLE 1

MICRO-ORGANISM COUNTS OBTAINED FROM WASTEWATER

MICROORGANISM	NUMBER OF ORGANISMS PER ML											
	RUN 1			RUN 2			RUN 3			RUN 4		
	1*	2**	3***	1	2	3	1	2	3	1	2	3
TOTAL	9.6×10^5	5.8×10^3	<100	9.6×10^5	2.7×10^5	4.3×10^3	4.9×10^6	1.1×10^5	3.2×10^2	6.0×10^6	8.5×10^4	1.5×10^3
COLIFORM	2.8×10^5	1.2×10^3	<1	4.0×10^5	1.1×10^4	<1	8.5×10^5	6.8×10^3	<1	5.1×10^5	4.1×10^3	<1
ENTEROCOCCUS	2.5×10^3	7.1×10^1	1.1×10^1	1.7×10^3	4.1×10^2	2.2×10^1	1.2×10^3	4.0	<1	7.4×10^3	1.9×10^2	2.0
SPOREFORMERS	1.2×10^1	3.9×10^1	5.0	3.7×10^1	1.3×10^2	2.0×10^1	1.3×10^1	3.0	<1	7.0	<1	<1
VIRUS	present	present	present	present	present	present	-	-	-	-	-	-

* = untreated sewage

** = effluent from Bloc process

*** = effluent irradiated at 2.4×10^5 rads

TABLE 2

CHEMICAL ANALYSES OF WASTEWATER

PARAMETERS	RUN 1		RUN 2		RUN 3		RUN 4	
	1*	2**	1	2	1	2	1	2
BOD	16	7.5	240	130	13	7.0	22	11
COD	45	45	860	760	100	60	60	60
TOC	25	25	308	251	19	22	30	30
TOTAL KJELDAHL NITROGEN	23	23	55	65	3.0	5.0	12	13
NITRITE	0.23	1.1	0.07	1.1	0.33	2.0	-	-
ANIONIC DETERGENTS AS ABS	0.4	0.1	0.4	0.4	0.2	0.1	0.4	0.3

*1 - plant effluent

**2 - irradiated plant effluent

TABLE 3

CHEMICAL ANALYSES OF TREATED AND IRRADIATED WASTEWATER

PARAMETER	RUN A			RUN B		
	1*	2**	3***	1	2	3
BOD	3.0	2.0	4.0	15.0	6.0	10.0
COD	30	25	20	45	35	55
TOC	14	9	8	22	13	19
ANIONIC DETERGENTS AS ABS	0.2	0.2	0.2	0.3	0.1	0.2
NITROGEN TOTAL KJELDAHL	1.4	1.4	0.8	3.0	2.5	4.0
NITRITE	0.07	1.4	1.5	0.11	1.2	1.2
NITRATE	20	20	20	15	14	14
PHOSPHORUS AS P. TOTAL	10	10	11	11	9.0	11
SOLUBLE	8.0	8.0	8.0	7.6	7.9	8.0

*1 - plant effluent

**2 - irradiated plant effluent

***3 - irradiated plant effluent seeded with fresh settled sewage

TABLE 4

CHEMICAL ANALYSIS OF SEWAGE EFFLUENTS TREATED BY IRRADIATION AND DE FILTRATION

		BOD	COD	TOC	TOTAL P	TOTAL KJELDAHL N
Run A	1	10	60	16	10	7.5
	2	4.5	40	11	11	3.0
	3	6.5	60	17	11	3.4
	4	4.0	40	9	8.8	3.8
Run B	1	9.5	50	18	3.2	2.5
	2	6.5	30	13	3.0	2.0
	3	7.5	40	14	3.0	2.5
	4	8.0	40	16	3.0	2.5
Run C	1	3.5	30	13	5.0	2.0
	2	1.0	20	13	4.6	2.0
	3	3.0	20	12	5.2	2.0
	4	2.5	20	12	4.7	2.0

1 - secondary sewage effluent; 2 - secondary sewage effluent filtered through DE filter; 3 - secondary sewage effluent, irradiated at 2.35 x 10^5 rads; 4 - secondary sewage effluent, irradiated at 2.35 x 10^5 rads and filtered through DE filter.

TABLE 5

CHLOROPHYLL ANALYSIS OF SEWAGE EFFLUENTS TREATED BY IRRADIATION

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	RUN A Undiluted	RUN A Diluted 1:10*	RUN B Undiluted	RUN B Diluted 1:10	RUN C Undiluted	RUN C Diluted 1:10
1. Secondary Effluent	53	15	19	4.8	20	12
2. Secondary Effluent DE Filtered	9.2	4.5	19	4.8	5.3	15
3. Secondary Effluent - Irradiated	6.8	10.0	2.4	5.0	5.6	24
4. Secondary Effluent - Irradiated and DE Filtered	3.8	19.0	7.8	10.0	2.4	5.6

* - the diluent was water from Gull Lake, Ontario (Average BOD - 1.6, COD 16, total N - 0.65 total P - 0.33 ppm), after filtration through a 0.45 μ Millipore filter.

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